

## The Upper Limit of Physiological Cardiac Hypertrophy in Elite Male Athletes

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**Abstract: Problem statement:** Establishment of upper normal limits of physiological hypertrophy in response to physical training is important in the differentiation of physiological and pathological left ventricular hypertrophy. The goal of our study was to investigate the normal upper limits of cardiac dimensions in elite athletes in Jordan in different types of sports (8 soccer players, 8 sprinters, 8 long distance runners, 6 weight lifters, 6 body builders). **Approach:** A total of 36 male athletes age  $25 \pm 5$  years of age, representing various sports were examined using standard two-dimensional guided M-mode and Doppler echocardiography to evaluate cardiac dimensions. **Results:** Results showed that 36 male athletes, 24 (66.6%) presented with LVEDD  $\geq 50$  mm with an upper limits of 53.4 mm sd 3.15, only 12 subjects (33.3%) presented with wall thickness values  $\geq 11$  mm, sd 0.53. None were found to have maximum wall thickness greater than 13 mm. There was a significant difference ( $p < 0.05$ ) between investigated sports in the left ventricular mass and left ventricular mass index in favor of endurance athletes. Systolic and diastolic blood pressure function was within normal limits for all athletes. Results from the present study suggested that upper normal limits for LV wall thickness and LV mass are 11.0 mm and 235.4 g m for elite male Jordanian athletes. **Conclusion:** There is a sport-specific left ventricular adaptation, the endurance heart differ significantly from the rest of the athletes investigated heart.

**Key words:** Athlete's heart, echocardiograph, left ventricular hypertrophy, cardiac dimension

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### INTRODUCTION

The adaptation of the heart to long-term regular physical training leads to cardiac morphological changes, including increased left ventricular cavity and wall thickness, (LV) end-diastolic cavity diameter, LV end-systolic Diameter and LV mass, described as athlete's heart (Pluim *et al.*, 2000; Spirito *et al.*, 1994; Pelliccia *et al.*, 1996; Dorn and Force, 2005; Sakamoto *et al.*, 2006; Urhausen and Wilfried, 1999). Cardiac hypertrophy induced by training was associated with better systolic and diastolic function and with less cardiac fibrosis suggesting that the adaptive mechanisms may exist in exercise-induced hypertrophy (Sakamoto *et al.*, 2006; Urhausen and Wilfried, 1999). Sport-specific adaptations and differentiation of an athlete's heart were described 100 years ago (Morganroth *et al.*, 1975; Landry *et al.*, 1985; Hoogsteen *et al.*, 2004). Several studies suggested that the precise alterations in cardiac structure associated with training may differ depending on the type of athletic activity (Pluim *et al.*, 2000; Pelliccia *et al.*,

1996; Landry *et al.*, 1985; George *et al.*, 1991; Pearson *et al.*, 1986).

Athletes involved in predominately static exercise, such as bodybuilders, have been found to have more concentric hypertrophy (in which wall thickness is increased in proportion to internal diameter (McDougall *et al.*, 1985; Karjalainen *et al.*, 1997). Whereas those involved in dynamic exercise, such as long distance runners, have more eccentric hypertrophy (Pelliccia *et al.*, 1996; Landry *et al.*, 1985; Schaier *et al.*, 1992; Shapiro, 1992; Levine *et al.*, 1991) (in which wall thickness is proportional to internal diastolic diameter). The morphological concept of the athlete heart have been enhanced and clarified over the last 10 years by echocardiography (Sahn *et al.*, 1978). The development and use of echocardiography allowed a more detailed interrogation of cardiac structure and function.

A standard Doppler echocardiography has proved to be an important tool to examine structural and functional adaptation of the heart in many intensive sport's training (Lauer *et al.*, 1992; Mockel and Stork,

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1996; Maista *et al.*, 2001; Longhurst *et al.*, 1980; Bekaer *et al.*, 1981; Makan *et al.*, 2005) its probably the best available noninvasive method to determine cardiac structure (Whyte *et al.*, 2004; Feigenbaum *et al.*, 1968; Murray *et al.*, 1972; Pavlik *et al.*, 2005; DuBois and DuBois, 1915; Sahn *et al.*, 1978; Lapido, *et al.*, 1980; Leonardis De and Cinelli, 1986). To our knowledge there is now studies have addressed the upper normal limits of cardiac dimensions in elite athletes in Jordan in different types of sports, in this study we investigated five groups of highly trained athletes to establish possible differences in left ventricular adaptation.

The purpose of this study was to examine, by echocardiography, the upper limits cardiac dimensions in elite athletes in Jordan in different types of sports to establish possible differences in cardiac adaptation.

### MATERIALS AND METHODS

All subjects were recruited through advertisements and flyers distributed at the training sites. Subjects in this study were 36 athletes aged 25±5 years old representing various sports: 8 soccer players, 8 sprinters, 8 long distance runners, 6 weight lifters, 6 body builders, the mean years of training in all athletes were 10.2±2.8 years.

Height, weight and Body Surface Area (BSA) were determined for each athlete BSA were defined as height 0.725\*weight 0.425\*0.007184 (LeVy *et al.*, 1987). All subjects were elite competitors represented their country at international level, with ten years training experience. Subjects were free of cardiovascular disease according to the medical history and physical examination and 12 lead resting electrocardiograms taken at Jordan University hospital. All subjects gave informed consent and study protocol was approved by Jordan University and the Hospital of Jordan University and was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki.

None of the subjects were taking any medication that might affect cardiac morphology. Table 1 shows the physical characteristics of the subjects.

**Echocardiography:** Echocardiography was performed in all subjects using an 7.5 MHz liner array transducer and ultrasound system (Sonos 2000 Hewlett Packard and over, MA) with simultaneous ECG recording. Subjects were instructed to lie in the left lateral position and standard two-dimensional guided M-mode echocardiography was used to evaluate cardiac dimensions. M-mode images at the tips of the mitral valve leaflets were used to measure the following echocardiographic parameters, Inter-Ventricular Septal thickness during Diastole (IVSD), Left Ventricular Internal Diameter during Diastole, (LVIDD), Left

Ventricular Internal Diameter during Systole, (LVIDS) and Left Ventricular Posterior Free Wall during Diastole (LVPWT). All measures were taken in accordance with the guidelines set by the American Society of Echocardiography (Hidick-Smith and Shapiro, 2001). Three to five consecutive measures were made and the average was taken by a single, experienced sonographer. Left Ventricular Mass (LVM) was calculated using a previously validated (Finkelhor *et al.*, 1986), formula:

$$\{LVM (g) = [1.04[ (LVID+LVPWT+IVSD)3-LVIDS]^{3 \times 0.8}$$

and left ventricular mass index by dividing LV mass by body surface area.

Echocardiography was performed using 7.5 MHz transducer to assess diastolic function. A two dimensional apical four-chamber view was imaged, taking care to maximize the diameter of the mitral valve annulus. Pulsed wave Doppler interrogation of mitral valve inflow velocity was performed with the alignment of the sample volume cursor parallel to the flow at the level of the mitral annulus. The Doppler velocity curves of the three to five consecutive cardiac cycles were digitized through the darkest grey scale and the parameter obtained were averaged. Peak early filling (E wave) and peak late filling (A wave) velocities were measured and the ratio of early to late diastolic filling (E, A) was calculated.

In the present study, to assure accuracy in interpreting echocardiographic data, the data were scrutinized by a cardiologist and where discrepancies existed the echo was re-evaluated. Intra-observer coefficients of variation of IVSD, LVIDD, LVPWT and LVM were 3.4, 2.8, 4.9, 2.8 and 4.9% respectively. These results are similar to those reported in previous studies and represent ~1 mm for all cardiac structures measured (DuBois and DuBois, 1915; Douglas *et al.*, 1986; Fagard, 1996).

**Statistical analysis:** Statistical analysis was carried out using SPSS package, a descriptive statistic (mean, std. deviation, kurtosis, skewness, minimum and maximum and pearson product moment) and analytic statistic( test of homogeneity of variance, one way ANOVA, non parametric test, kruskal-wallist test, dunnett post hoc test) were performed. A value of (p<0.05) was considered statistically significant.

Table 1: Demographic characteristics

Sport	N	Age (years)	Weight (kg)	Height (cm)	BSA (m <sup>2</sup> )
Soccer	8	25.20	76.32	1.79	1.94
sprinters	8	26.75	64.62	1.70	1.87
Long distance (endurance)	8	25.87	60.62	1.72	1.72
Weight lifting	8	23.66	77.66	1.70	1.91
Bodybuilding	6	24.66	77.83	1.79	1.96
Group means	36	25.41	70.72	1.74	1.85

**RESULTS**

Table 2 gives means and standard deviations of the measured values of LVIDD, LVISD, LVM, LVMI, LVPWT and IVSD.

**Mean cardiac dimensions:**

**L ventricular mass:** The endurance players had mean values of LV mass higher than the rest of the players in other groups. Values ranged from 206-259 g m (mean 235.037 g m). The values were statistically significant for all groups ranged from 148-259 g m. When all groups were considered together the L ventricular mass was statistically significant.

**Interventricular septum:** The mean value for IVSP for endurance group was higher than the rest of the groups with values ranged from 11.0-12.0 mm.

**L ventricular mass index:** The mean of L ventricular mass index for each group was statistically significant, values ranged from 76-137.9 g m<sup>-2</sup> with the endurance players have the highest values, there values ranged from 112-159 g m<sup>-2</sup> with mean values 137.87 g m<sup>-2</sup>.

**LV posterior wall:** The mean value of the left ventricular posterior wall thickness for endurance athletes was significantly higher than that of athletes of other sports in the study, the mean values ranged from 11 -12 mm.

**Left Ventricular end-Diastolic Diameter (LVIDD):** The mean values for the Left ventricular end-diastolic diameter for each group of sports were ranged from 47-

53.37 mm with mean values 51.33 mm. In additions the endurance group values was different than the rest of groups 48-57 mm with mean values 53.37 mm. The difference was not statistically significant. Endurance runners had the largest and body builder had the smallest LV end diastolic diameter.

**Left Ventricular end-Systolic Diameter (LVISD):** The mean values for the Left ventricular end-systolic diameter for each group of sports were ranged from 31-38.62 mm. In additions the sprinters group values was the highest, ranged from 35-43 mm with a mean of 38.62.

Of the 36 athletes none of them presented with wall thickness values greater than 13 mm. LVIDD was less than 60 mm in all subjects. All subjects had LVMI under 140 g m<sup>-2</sup> (mean 111.77 g m<sup>-2</sup>) with endurance players 137.87 g m<sup>-2</sup> a LVMI value equal to or greater than 130 g m<sup>-2</sup> was considered as a criterion for the presence of left ventricular hypertrophy (Pelliccia and Maron, 1997).

LV Mss and LVMI were significantly greater in endurance players than the rest of the players in this study, 235.37 (g m) and 137.87(g m<sup>2</sup>) respectively shown in Fig. 1 and 2. IVSD, LVIDD, LVISD were not significant Fig. 3 and 4. According to Hidick-Smith and Shapiro (2001) and Thompason (2000) Left ventricular mass and more particularly mass index are the benchmarks by which LV hypertrophy should be judged.

The echocardiographic dimensions means and standard deviations are shown in Table 2.

Table 2: The echocardiographic dimensions post-training

	Soccer		Speed		Long distance (endurance)		Weight lifting		Bodybuilding	
	M	Range	M	Range	M	Range	M	Range	M	Range
LVIDD (mm)	51.37	50-54	51.75	47-57	53.37	48-57	50.33	49-53	49.83	48-56
	sd		sd		sd		sd		sd	
	1.407		2.91		3.15		1.63		3.25	
LVISD (mm)	37.37	34-41	38.62	35-43	37.25	33-41	35.66	33-38	35.0	31-39
	sd		sd		sd		sd		sd	
	2.72		2.77		2.71		2.25		3.74	
LVM (g m)	206.75	148-263	205.25	189-222	235.37	206-259(*)	200.5	152-226	184.5	149-240
	sd		sd		sd		sd		sd	
	42.21		12.98		20.89		28.07		36.99	
LVMI (g m <sup>-2</sup> )	106.01	79-132	116.87	106-132	137.87	112-159(*)	104.16	89-120	93.93	75-119
	sd		sd		sd		sd		sd	
	20.34		9.77		17.69		12.05		15.98	
LVPWT (mm)	10.50	9-12	9.75	9-11	11.0	11-12	10.33	9-11	9.66	
	sd		sd		sd		sd		sd	
	1.41		0.707		0.53		0.98		1.36	
IVSD (mm)	9.38	12.1- 11.1	10.37	9.0- 12.0	11.25	11.0-12.0	10.83	9.0-12	10.50	10-12
	sd		sd		sd		sd		sd	
	3.66		1.06		0.46		0.81		0.83	

Were: LVIDD: Left Ventricular end-Diastolic Diameter, LVISD: Left Ventricular end-Systolic Diameter, LVM: Left Ventricular Mass, mass, LVMI: Left Ventricular Mass Index, LVPWT: Left Ventricular Posterior Wall Thickness, IVSD: Inter-Ventricular Septal Thickness during Diastole

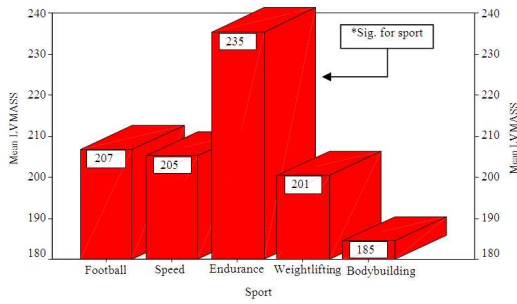


Fig. 1: Mean for LVMASS according to type of sport

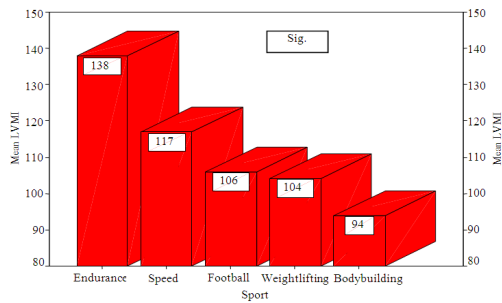


Fig. 2: Mean for LVMI according to type of sport

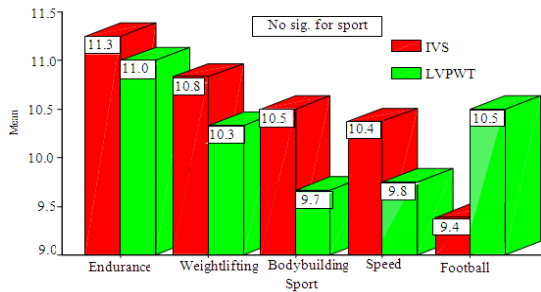


Fig. 3: Mean for LVPWT and IVSD

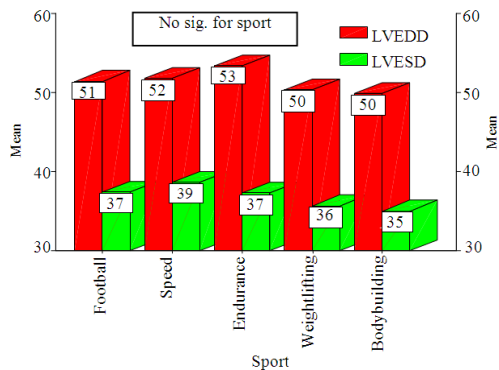


Fig. 4: Mean for LVIDD and LVIDS according to type of sport

## DISCUSSION

This was the first study to specifically describe the full range of echocardiographically determined the upper limit of the left ventricular hypertrophy in elite athletic male in Jordan. In our study we compared the myocardial adaptations of different types of sports including long and short distances (endurance and sprinters) runners, soccer, weight lifting and body building. There is a sport-specific left ventricular adaptation between athletes in our study, similar to the finding of other researchers (Clifford *et al.*, 1994; Fagard *et al.*, 1984). The majority of the subjects exhibited abnormal geometry, significant increase was found in the endurance athletes where, in other groups of the study there was less pronounced increase. With subjects involved in predominately static exercise, bodybuilders and weight lifting, (33.4%) have been found to have more concentric hypertrophy, whereas those involved in dynamic exercise, (long and short distance runners (66.6%) have more eccentric hypertrophy. The present study is consistent with what has been described as the “athletic heart syndrome” (Pelliccia *et al.*, 1996; Pavlik *et al.*, 2001; Abernethy *et al.*, 2003). The findings of our study are similar to those observed in athletes in many studies. Left ventricular mass were significantly greater in endurance athletes than in other athletes of different sports in this study. That’s similar to the finding of others.

In other studies the left ventricular diastolic diameters were larger than those of their Jordanians counterparts. That’s probably due to more intensive and prolonged training time (all our subjects were amateur even though they represented their country at the international level). However, the adaptations to exercise in this population are more likely to reflect the workload of training and the training season which was lower and shorter than the workload and the training season in other populations in other studies. Fagard *et al.* (1984) have found significant variation in LV wall thickness according to the level of exercise performed.

It has been suggested that maximum wall thickness rarely exceeds 13 mm in athlete’s heart (Pelliccia *et al.*, 1996). And that maximum wall thickness greater than this range is suggestive of hypertrophic cardiomyopathy. None of our subjects had maximal wall thickness  $\geq 11$  mm. No subjects demonstrated characteristics of hypertrophic cardiomyopathy or any other echocardiographic evidence of cardio pathology. The largest wall thickness values observed in our study was for endurance athletes (11 mm) this is in agreement with (Morganroth *et al.*, 1975; Murray *et al.*, 1972) and was lower than the finding of (Pelliccia *et al.*, 1996).

Abernthy *et al.* (2003) found a mean septal wall thickness of 11.2 mm in a group of professional American Football players, where in other study he found septal wall thicknesses of 11.1 mm in professional cyclists competing in the Tour de France. Pelliccia *et al.* (1996) reported in the largest echocardiographic study that a mean septal thickness of 10.1 mm in a broad cross-section of Italian National team members. All athletes demonstrated normal diastolic and systolic function, suggesting a physiological enlargement.

The small sample size and the lack of female participants limit confidence in the study's conclusions. Future studies should explore cardiac adaptations in female athlete in Jordan.

### CONCLUSION

Results from the present study suggested that upper limits for left ventricular mass and left ventricular mass index are 235(g m) and 137.87(g m<sup>-2</sup>) for elite male Jordanian. those adaptive changes were similar to those found in athletes in other studies, However, due to higher training standard and professionalism among athletes of other nations the out-come of there measurement was more profound when compared with the Jordanian athletes. There is a sport-specific left ventricular adaptation within athletes, the endurance heart differ significantly from the rest of the athletes in the study.

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### REFERENCES

Abernthy, W.B., J.K. Choo and A.M. Hutter, 2003. Echocardiographic characteristics of professional football players. *J. Am. Coll. Cardiol.*, 41: 280-284. PMID: 12535823

Abernthy, W.B., J.K. Choo, and A.M. Hutter, Jr., 2003. Echocardiographic characteristics of professional football players. *J. Am. Coll. Cardiol.*, 41: 280-284. PMID: 12535823

Bekaer, I., J.L. Pannler, C. Van de Weghe, J.P Van Durme and D.L Clement *et al.*, 1981. Noninvasive evaluation of cardiac function in professional cyclists. *Br. Hear. J.*, 45: 213-218. PMID: PMC482513

Clifford, P.S., B. Hanel and N.H. Secher, 1994. Arterial blood pressure response to rowing. *Med. Sci. Sports Exerc.*, 26: 715-719. PMID: 8052112

Dorn, G.W. and T. Force, 2005. Protein kinase cascades in the regulation of cardiac hypertrophy. *J. Clin. Invest.*, 115: 527-537. PMID: 15765134

Douglas, P.S., M.L. O'Toole, D.B. Hiller and N. Reichek, 1986. Left ventricular structure and function by echocardiography in ultraendurance athletes. *Am. J. Cardiol.*, 58: 805-809. <http://cat.inist.fr/?aModele=afficheN&cpsidt=7954706>

DuBois, D. and E.F. DuBois, 1915. Measurement of surface area in man. *Arch. Int. Med.*, 15: 868-881. [http://archinte.ama-assn.org/cgi/content/summary/XV/5\\_2/868](http://archinte.ama-assn.org/cgi/content/summary/XV/5_2/868)

Fagard, R., A. Aubert, J. Statesen, E.V. Eynde and L. Vanhees *et al.*, 1984. Cardica structure and function in cyclists and runners comparative echocardiographic study. *Br. Heart J.*, 52: 124-129. PMID: PMC481600

Fagard, R.H., 1996. Athlete's heart: A meta-analysis of the echocardiographic experience. *Int. J. Sports Med.*, 17: 140-144. PMID: 9119534

Feigenbaum, H., R.L. Popp, J.N. Chip and C.L. Haine, 1968. Left ventricular wall thickness measurement by ultrasound. *Arch. Intern. Med.*, 121: 391-395. <http://archinte.ama-assn.org/cgi/content/abstract/121/5/391>

Finkelhor, R.S., L.J. Hanak and R.C. Behler, 1986. Left ventricular filling in endurance-trained subjects. *J. Am. Coll. Cardiol.*, 8: 289-293. PMID: 3525649

George, K.P., L.A. Wolfe and G.W. Burggraf, 1991. The athletic heart syndrome. *Sports Med.*, 11: 300-330. PMID: 1829849

Hidick-Smith, D. and L. Shapiro, 2001. Echocardiographic differentiation of pathological and physiological left ventricular hypertrophy. *Heart*, 85: 615-619. PMID: PMC1729776

Hoogsteen, J., A. Hoogeveen, H. Schaffers and P.F. Wijn, 2004. Myocardial adaptation in different endurance sports: An echocardiographic study. *Int. J. Cardiovasc. Image.*, 20: 19-26. PMID: 15055817

Karjalainen, J., M. Mantysaari, M. Viitasalo and U. Kujala, 1997. Left ventricular mass, geometry and filling in endurance athletes: Association with exercise blood pressure. *J. Applied Physiol.*, 82: 531-537. <http://cat.inist.fr/?aModele=afficheN&cpsidt=2581926>

- Landry, F., C. Bouchard and J. Dumesnil, 1985. Cardiac dimension changes with endurance training indications of a genotype dependency. *J. Am. Med. Assoc.*, 254: 77-80. PMID: 4039766
- Lapido, G.O.A., F.G. Dunn, T.H. Pringle, B. Bastian and Lawrie, 1980. TDV Serial measurements of left ventricular dimensions by echocardiography. Assessment of week-to-week, inter-and inobserver variability in normal subjects and patients with valvular heart disease. *Br. Heart J.*, 44: 284-288.  
<http://heart.bmj.com/cgi/content/abstract/44/3/284>
- Lauer, M., D. Levy, M. Keaven Anderson and J. Plehn, 1992. Is there a relationship between exercise systolic blood pressure response and left ventricular mass. *Ann. Int. Med.*, 16: 203-210.  
<http://cat.inist.fr/?aModele=afficheN&cpsid=5256425>
- Leonardis De, V. and P. Cinelli, 1986. Evidence of no interobserver variability in M-mode echocardiography. *Clin. Cardiol.*, 9: 324-327. PMID: 3731555
- Levine, B., L. Lane, J. Buckley, D. Friedman and G. Blomqvist, 1991. Left ventricular pressure volume and Frank-Starling relations in endurance athletes. *Circulation*, 84: 1016-1023. PMID: 1884438
- LeVy, D., D.D. Savage, R.J. Garrison, K.M. Anderson and W.B. Kannell *et al.*, 1987. Echocardiographic criteria for left ventricular hypertrophy: The Framingham heart study. *Am. J. Cardiol.*, 59: 656-960. PMID: 2952002
- Longhurst, J.C., A.R. Keily, W.J. Gonyea and J.H. Mitchell, 1980. Echocardiographic left ventricular masses in distance runners and weight lifters. *J. Applied Physiol.*, 48: 154-162.  
<http://jap.physiology.org/cgi/content/abstract/48/1/154>
- Maista, E., H. Kaarma and E. Tiit, 2001. Connection between heart measurements and body dimension of 15-years-old girls. *Anthropol.*, 10: 153-167.
- Makan, J., S. Sharma, S. Firoozi, G. Whyte and P.G. Jackson *et al.*, 2005. Physiological upper limits of ventricular cavity size in highly trained adolescent athletes. *Heart*, 91: 495-499.  
<http://heart.bmj.com/cgi/content/abstract/91/4/495>
- McDougall, J.D., D. Tuxen, D.G. Sale, J.R. Moroz and J.R. Sutton, 1985. Arterial blood pressure response to heavy resistance exercise. *Am. J. Physiol.*, 58: 785-790. PMID: 3980383
- Mockel, M. and T. Stork, 1996. Diastolic function in various forms of left ventricular hypertrophy: Contribution of active Doppler stress echo. *Int. J. Sports Med.*, 17: S184-90.  
<http://cat.inist.fr/?aModele=afficheN&cpsid=2544257>
- Morganroth, J., B.J. Maron, W.L. Henry and S.E. Epstein, 1975. Comparative left ventricular dimensions in trained athletes. *Ann. Intern. Med.*, 82: 521-524. PMID: 1119766
- Murray, J.A., W.B. Joonhston and J.M. Rcid, 1972. Echocardiographic determination of left ventricular dimension volumes and performance. *Am. J. Cardiol.*, 30: 252-257. PMID: 5044484
- Pavlik, G., D. Kemeny, Z. Kneffel, M. Petrekanits and P. Horvath *et al.*, 2005. Echocardiographic data in Hungarian top-level water polo players. *Med. Sci. Sports Exerc.*, 37: 323-328.  
<http://cat.inist.fr/?aModele=afficheN&cpsid=16477168>
- Pavlik, G., Z. Olexo, P. Osvath, Z. Sido and R. Frenkl, 2001. Echocardiographic characteristic of male athlete of different age. *Br. J. Sports Med.*, 35: 95-99. PMID: PMC1724312
- Pearson, A.C., M. Schiff, D. Mrosek, A.J. Labovitz and G.A. Williams, 1986. Left ventricular diastolic function in weight lifters. *Am. J. Cardiol.*, 58: 1254-1259. PMID: 2947454
- Pelliccia, A. and B.J. Maron, 1997. Outer limits of the athlete's heart, the effects of gender and relevance to the differential diagnosis with primary cardiac disease. *Cardiol. Clin.*, 15: 381-396.  
<http://cat.inist.fr/?aModele=afficheN&cpsid=10179796>
- Pelliccia, A., B.J. Maron, F. Culasso, A. Spataro and G. Caselli, 1996. Athlete's heart in women. Echocardiographic characterization of highly trained elite female athletes. *J. Am. Med. Assoc.*, 276: 211-215. PMID: 8667565
- Pluim, B.M., A.H. Zwiderman, A. van der Laarse and E.E. van der Wall, 2000. The athlete's heart. A meta-analysis of cardiac structure and function. *Circulation*, 101: 336-344. PMID: 10645932
- Sahn, D.J., A. DeMaria, J. Kisslo and A. Weyman, 1978. Recommendations regarding quantitation in M-mode echocardiography: Results of a survey of echocardiographic measurements. *Circulation*, 58: 1072-1083. PMID: 709763
- Sakamoto, M., T. Minamino, H. Toko, Y. Kayama and Y. Zou *et al.*, 2006. Up regulation of heat shock transcription factor 1 plays a critical role in adaptive cardiac hypertrophy. *Circ. Res.*, 99: 1411-1418.  
<http://cat.inist.fr/?aModele=afficheN&cpsid=18360725>
- Schaier, J., P. Stein, S. Keteyian, F. Fedel and J. Ehrman *et al.*, 1992. Left ventricular response to sub maximal exercise in endurance trained athletes and sedentary adults. *Am. J. Cardiol.*, 70: 930-933. PMID: 1529949

- Shapiro, L., 1992. Morphologic consequences of systematic training. *Cardiol. Clin.*, 10: 219-226. PMID: 1533563
- Spirito, P., A. Pellicia, M.A. Proschan, M. Granata and A. Spataro *et al.*, 1994. Morphology of the "athlete's heart" assessed by echocardiography in 947 elite athletes representing 27 sports. *Am. J. Cardiol.*, 74: 802-806. PMID: 7942554
- Thompson, P.D., 2000. *Exercise and Sports Cardiology*. 1st Edn., McGraw-Hill, USA., ISBN: 10: 0071347739, pp: 504.
- Urhausen, A. and K. Wilfried, 1999. Sport-specific adaptations and differentiation of the athlete's heart. *Sports Med.*, 22: 237-244. PMID: 10565550
- Whyte, G., K. George, S. Sharma, S. Firoozi and N. Stephens *et al.*, 2004. The upper limit of physiological cardiac hypertrophy in elite male and female athletes: The British experience. *Eur. J. Applied Physiol.*, 92: 592-597. DOI: 10.1007/s00421-004-1052-2